

EFFECT OF SNOW COVER ON OBSTACLE PERFORMANCE OF VEHICLES - B. HANAMOTO

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EFFECT OF SNOW COVER
ON OBSTACLE PERFORMANCE OF VEHICLES

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1. INTRODUCTION

The operation of vehicles in the off-road environment becomes a complex interaction between vehicle, terrain and man. Under temperate conditions, the off-road environment can be described in terms of soft soil, hard or rough ground, geometric obstacles, vegetation and the riverine environment. Prediction of vehicle performance in these terrain conditions has been and is continuing to be studied. Soft soils are treated in terms of soil strength properties and vehicle performance characteristics such as sinkage, motion resistance and tractive effort. Hard ground analysis is primarily concerned with vibration and its effect on vehicle and occupants. Geometric obstacles are studied with obstacle crossing in mind. Vegetation, which includes trees, tall grass and brush, is considered as an obstacle as well as a hinderance to visibility. The riverine environment is treated as consisting of two parts, the bank and the waterway. Bank problems include soil conditions, vegetation and geometry while entering or exiting, whereas water problems include floating, fording and maneuverability depending on depth, width and velocity of the waterways. Then, for operation in a selected area, these terrain conditions do occur randomly as well as in combination, thereby increasing the complexity of the problems. When an arctic or cold climate is imposed on this same terrain, the environmental conditions present an entirely different situation for the vehicle. With snow cover, soft ground is no longer a problem since soft soil becomes frozen and snow covered and hard ground is no longer a problem because vibration producing roughness is smoothed out by snow cover. Geometric obstacles also become snow covered, changing both in magnitude and shape as

obstacles. Vegetation as an obstacle remains except for grass and brush; but except for evergreen trees, changes in visibility of obstacles are quite drastic under winter conditions. The riverine environment also undergoes a drastic change with waterways becoming frozen and banks snow covered and geometrically altered. The terrain descriptions required for performance prediction equations must therefore include different sets of inputs due to cold climate and snow cover.

2. GENERAL

a. Objective: The objective of this study is to investigate one phase of the alteration of terrain conditions due to snow cover. The study attempts to identify the contribution soft snow makes when combined with other terrain obstacles to the impedance of vehicle traffic.

b. Background: Studies of vehicle performance in obstacle fields have been reported by Brooks and Janosi, References 1 and 2.

Even though the analyses apply to highly idealized cases, an extension and modification of the obstacle crossing equations of Janosi to include snow cover will allow a more realistic prediction of vehicle performance in snow terrain when both geometric and surface properties are included.

Both wheeled and tracked vehicles have been considered crossing solid vertical walled steps and trenches and v-shaped crests and ditches. For operation over snow-covered terrain, wheeled vehicle travel is limited to only a select few such as the "VEXA" vehicles, Reference 3, or possibly the XM 808 Twister. Wheeled vehicle travel being an exception, only tracked vehicles will be considered in this snow cover-obstacle study.

The case of step crossing will be considered first. The condition for successful step negotiation is that the c.g. of the vehicle must pass beyond the vertical edge of the step, Fig. 1.

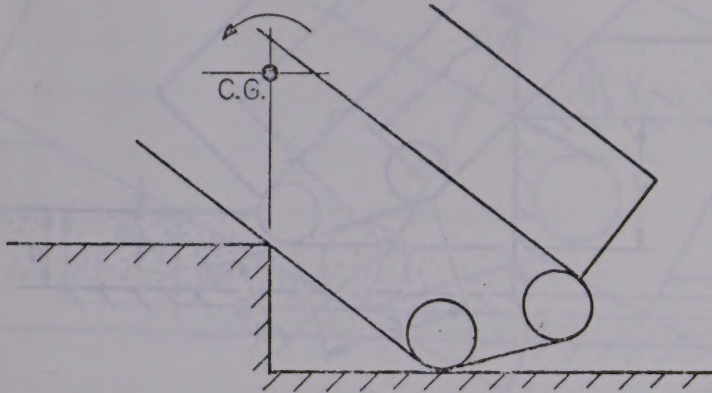


Figure 1

If the geometry of the vehicle or obstacle prevents this, immobilization occurs. Figure 2 depicts the situation of the snow covered obstacle. The computer program for predicting maximum step height, given vehicle dimensions and snow cover description in terms of snow depth, d , and snow strength parameters which allow for prediction of vehicle sinkage, Z_0 , are being prepared. Any snow strength parameters which predict vehicle sinkage may be used. In the present case the soil value system developed by the Land Locomotion Laboratory will be used to predict sinkage, Reference 4.

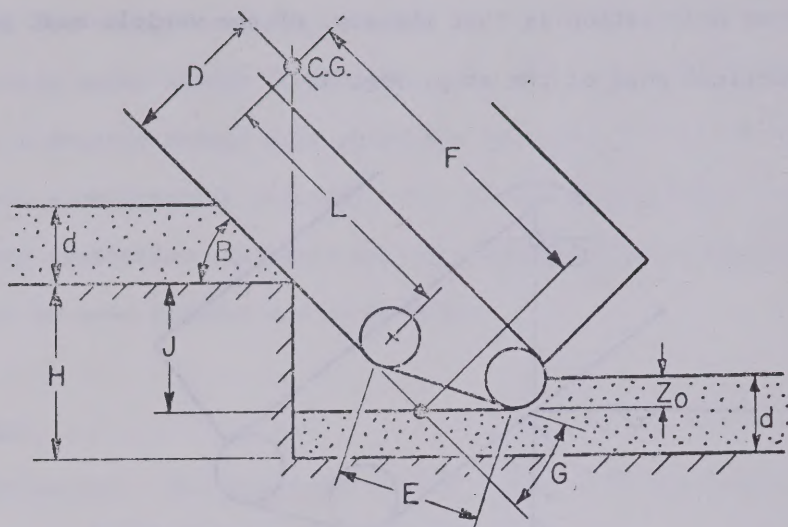


Figure 2

The step height negotiable in Figure 2 is given by:

$$J = \tan B \left[F \cos B - D \sin B \right]$$

and the maximum step height being:

$$H = J + d - Z_0$$

For vehicles with front end clearance dimensions, CF, H may be first limited by CF. In the case with a rear clearance problem, Fig. 3, H may be limited by CR.

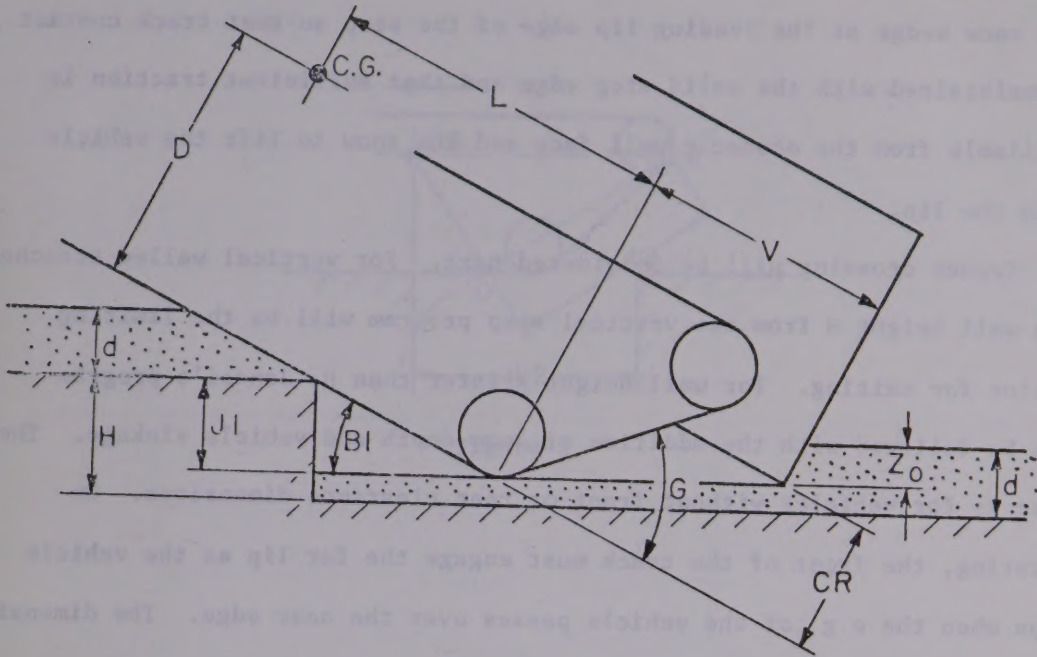


Figure 3

$$B1 = \tan^{-1} \frac{CR}{V}$$

$$J1 = \left[L - D \tan B1 \right] \sin B1$$

$$H = J1 + d - Z_0$$

The computer programs for these situations are also being prepared. Inputs for these programs include: L, D, E, G, CF, CR, V, W (weight of vehicle), b (track width), ℓ (track contact length) for the vehicle and k_c , k_ϕ , n and d as descriptors of the snow cover.

Assumptions made in the above cases are that the vehicle compacts the snow wedge at the leading lip edge of the step so that track contact is maintained with the solid step edge and that sufficient traction is available from the obstacle wall face and the snow to lift the vehicle onto the lip.

Trench crossing will be considered next. For vertical walled trenches, the wall height H from the vertical step program will be the limiting factor for exiting. For wall height greater than H , Janosi's program can be followed with the addition of snow depth and vehicle sinkage. The case is for vehicles without front or rear clearance dimensions. On entering, the front of the track must engage the far lip as the vehicle tips when the c.g. of the vehicle passes over the near edge. The dimension for the maximum width is W_1 , Figure 4.

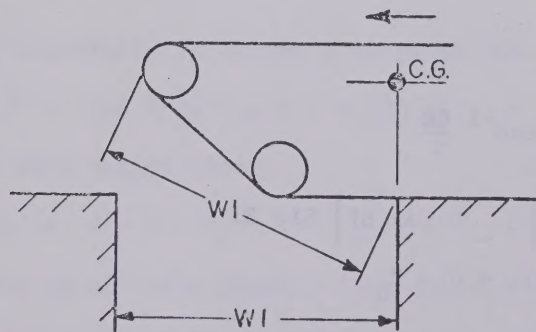


Figure 4

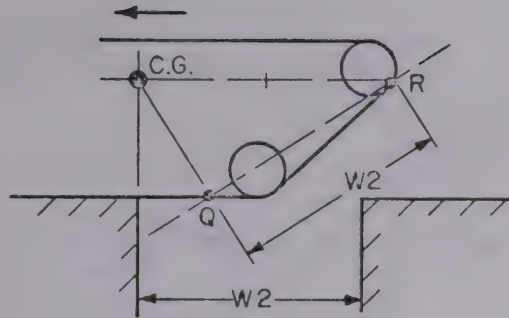


Figure 5

Figure 5 shows the case for the passage of the rear over the ditch without falling back. As the c.g. passes the far lip, the point R must engage the trailing edge. The maximum crossable ditch would be the lesser of W_1 or W_2 . When front or rear clearance dimensions are present on the vehicle, interference of these points either with the ground or with the obstacle constitutes immobilization. Figure 6 depicts the front end clearance problem.

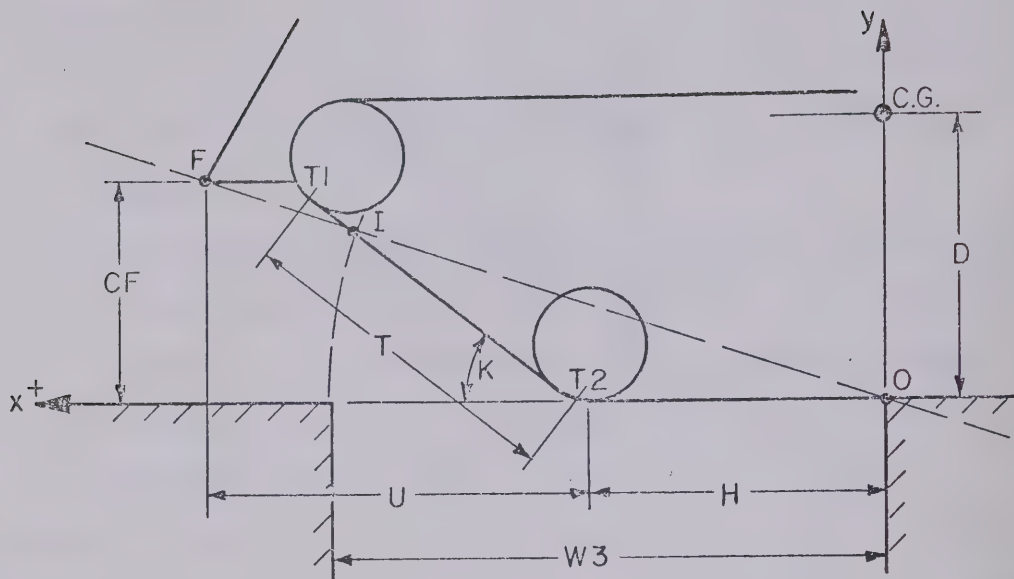


Figure 6

The line of front end clearance is $\overline{OF}$ and the front track element must come in contact with the far trench edge before reaching this level as the vehicle tips forward. $\overline{OI}$, the distance to the intersection point of $\overline{OF}$ and $\overline{T_1T_2}$ is the maximum trench width. Taking coordinate points as shown: $O(0,0)$, $F(U+H, CF)$, $T_1(H+\cos K, T \sin K)$, $T_2(H, 0)$; the slope of $\overline{T_1T_2} = m_1 = \tan K$. The slope of $\overline{OF} = m_2 = \overline{OF}/U+H$.

But the critical point is the contact point S on the rear element of the track with the clearance line $\overline{Q1 R1}$ which reduces the maximum trench width to $\overline{Q1S}$.

Given coordinate points as shown:

$$\phi (0, D), R1 (L + V, CR), P \left(\frac{L+V}{2}, \frac{D+CR}{2} \right)$$

The equation for the circle with center at P is:

$$\left[x - P(x) \right]^2 + \left[y - P(y) \right]^2 = \text{SQR} \left[R1(x) \right]^2 + \left[R1(y) - \phi(y) \right]^2$$

Of the two intercepts at $y = 0$, $Q1$ is the point of interest.

$$\text{Then } E = \tan^{-1} \overline{OQ1}/D$$

$$\text{and } F = G - E$$

$$\text{Letting } C2 = \pi - G$$

The maximum trench width $W4$ becomes:

$$W4 = \overline{Q1S} = \left[(L - \overline{OQ1}) \sin C2 \right] / \sin F$$

The maximum trench widths negotiable by vehicles with front and rear clearance dimensions are given by $W3$ or $W4$ regardless of whether the walls are vertical or sloped. For other conditions of sloped walls with gap widths greater than $W1$, $W2$, $W3$ or $W4$, exiting from these V-trenches becomes one of slope negotiation. Slope climbing ability is dependent on the strength of the snow covering the slope. If bearing and shear strength values are known, the negotiable slope angle can be approximated by $\tan^{-1} \frac{DP}{W}$, where

$$DP = H - R$$

$$DP = \text{Drawbar-pull (on the level)}$$

H = Total thrust available from snow

R = Motion resistance

W = Vehicle weight

TESTING SITE

Preliminary field tests were conducted at the Keweenaw Field Station in Houghton, Michigan, a station jointly supported by U. S. Army TACOM and USACRREL and operated by Michigan Technological University. Natural slopes as well as artificially constructed obstacles were used for the tests. The test course had been previously used for vehicle performance evaluation tests, Reference 5, and provided a ready and convenient test site.

TEST VEHICLE

The Snow-Trac, a lightweight tracked over-the-snow vehicle manufactured by Westerasmackiner of Sweden, one of the many vehicles of the fleet available at the Field Station was used as the test vehicle. Powered by an air-cooled Volkswagen, 4 cylinder OHV gasoline engine and fully enclosed and heated, the Snow-Trac proved ideal for these preliminary tests. Some vehicle characteristics are (Ref. 6):

Length	3640 mm (143.3 in.)
Width	1900 mm (65 in.)
Height	1981 mm (78 in.)
Ground Clearance	300 mm (12 in.)

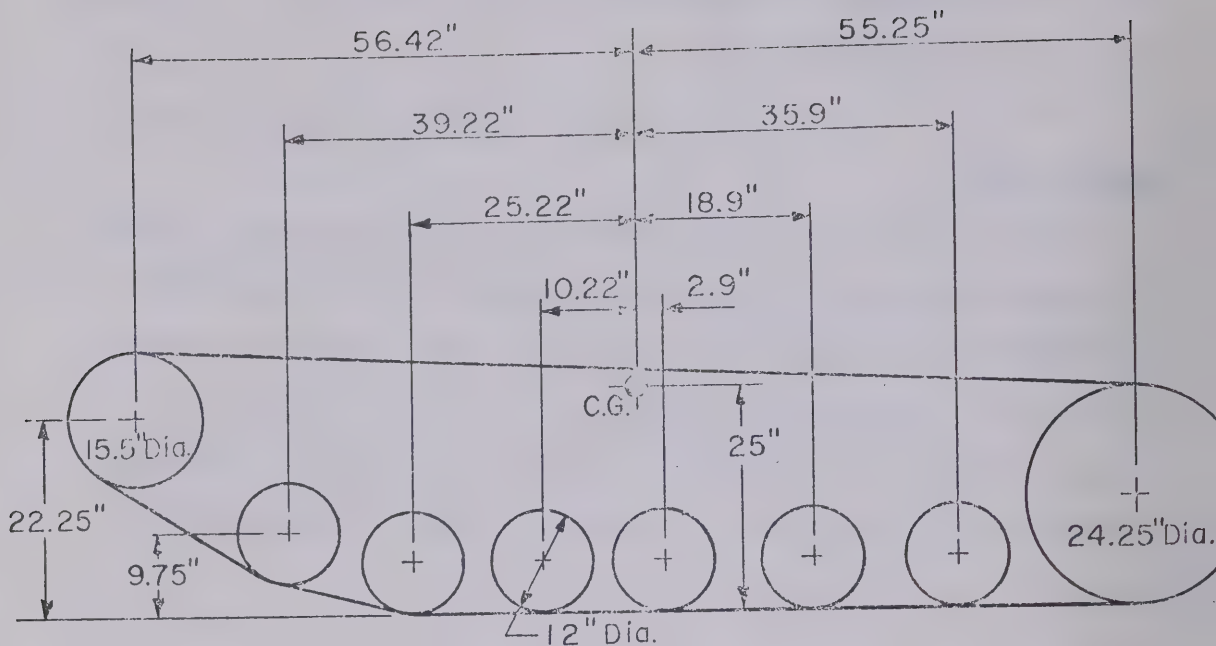


Figure 8

Vehicle dimensions are shown in Figure 8. The tracks, 18 inches wide, with a hard ground contact length of 80 inches, provide a ground pressure of approximately 1 psi for a vehicle weight of 3024 lbs. The driver operations are identical to an automobile, with steering by a conventional automotive type wheel. For follow-on tests, other vehicles of different weight and configuration should be used. The selection could include the M-113, Armored Personnel Carrier, the M-29C Weasel, the Swedish BV-202 2-unit articulated tracked carrier, and the two or three unit articulated tracked "COBRA" all of which are part of the vehicle fleet at the Field Station.

TESTING AND RESULTS

Natural slope climbing tests were conducted along the Portage Canal in West Hancock. The course was 100 ft in length with average slope of 24° in the uncovered state. The profile with snow cover is presented in Figure 9.

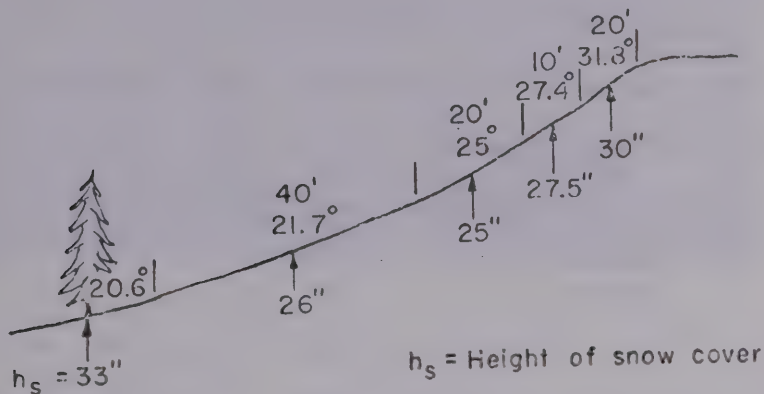


Figure 9

The measure of performance was speed when slopes were negotiable. The No-Go or immobilization slope conditions were of primary concern in these tests. Measurements recorded were slopes, cover depth and vertical density profiles.

Obstacle crossings were conducted at several locations. Two such obstacles, used in the performance evaluation of the "COBRA", Reference 7, were a natural earth bank with vertical walls, $5\frac{1}{2}$ ft high, and a solid concrete step, 42 in. high. A 90° V-trench, 42 in. deep, on the artificially constructed obstacle course was another that was used. A natural creek bed was also used in this portion of the tests. Measurements recorded were snow depth, slope, shape and vertical density profiles of the snow.

The results of the slope tests indicated that a speed reduction occurred when negotiating slopes which were snow covered compared to the snow free performance. The average speed to complete West Hancock No. 1, Reference 5, was 9.2 ft/sec over a 100-ft course. With snow cover over the same course, immobilization occurred 20 ft from the crest with an average speed of 4.0 ft/sec. In repeated tests, immobilization occurred on slopes of 31.0° , 27.5° , 29.0° , and 26.5° , averaging 28.5° . The snow density profile on these slopes is listed below:

<u>Depth</u>	<u>g/cc</u>	<u>Comments</u>
Surface	0.33	
4 in. below	0.38	Hard crust
8 in. below	0.29	Below crust

There were variations along the slopes used for these tests with certain spots having a very hard packed crust of 0.40 g/cc density. At the crest, the surface density measured 0.480 g/cc (ice and snow crust). Vehicle sinkage averaged between 1 and 2 in., riding over the crust. At immobilization, sinkages were between 5 and 10 in., where excessive track slippage in one spot caused weakening of the crust and breakage through. Views of the test slopes are shown in Photos 1 and 2.



Photo 1. Natural slope.



Photo 2. Natural slope.

Tests were also conducted in less dense snow in the same West Hancock area. The snow density profile was:

<u>Depth</u>	<u>g/cc</u>	<u>Comments</u>
Surface	0.21	New Snow
6 in. below	0.18	
12 in. below	0.21	
18 in. below	0.32	Slight crust

Under these conditions, the negotiable slope was reduced to 22°, with 25° marginal. Vehicle sinkages were 10, 9.0, 12.5, and 7.0 inches.

Crossing of a small creek with alder brush cover was conducted on Johnson's farm adjacent to the Houghton County Airport. Profiles, snow depths and density profile are shown in Figures 10 and 11.

Density for Site 1 and 2:

<u>Depth</u>	<u>g/cc</u>
Surface	0.17
6 in. below	0.25
12 in. below	0.26
18 in. below	0.26

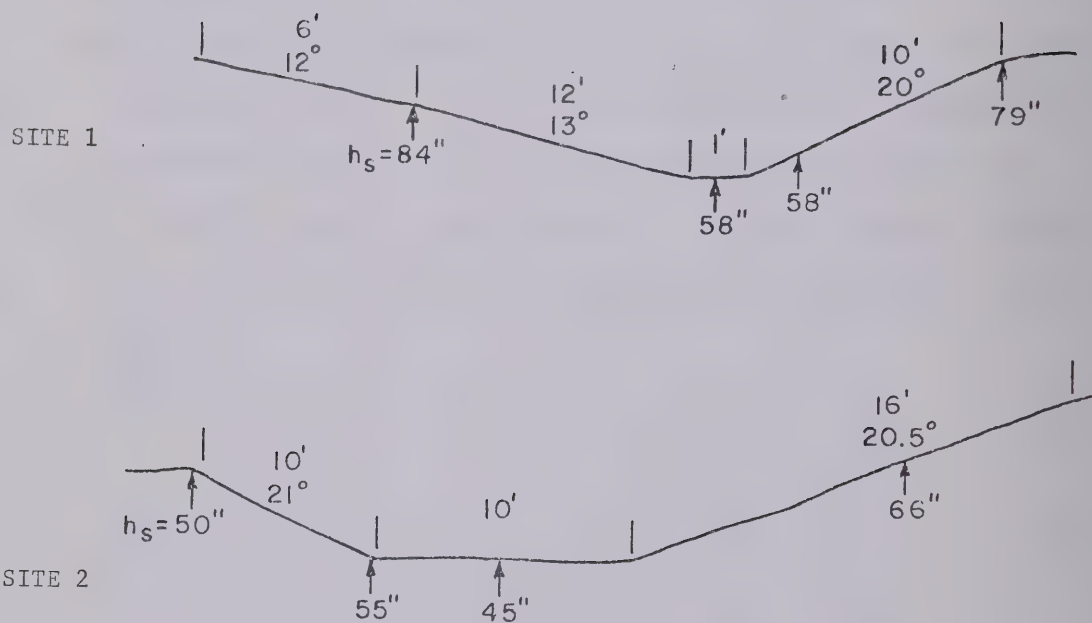


Figure 10

Density at immobilization point:

<u>Depth</u>	<u>g/cc</u>
Surface	0.25
6 in. below	0.26
12 in. below	0.25
18 in. below	0.24

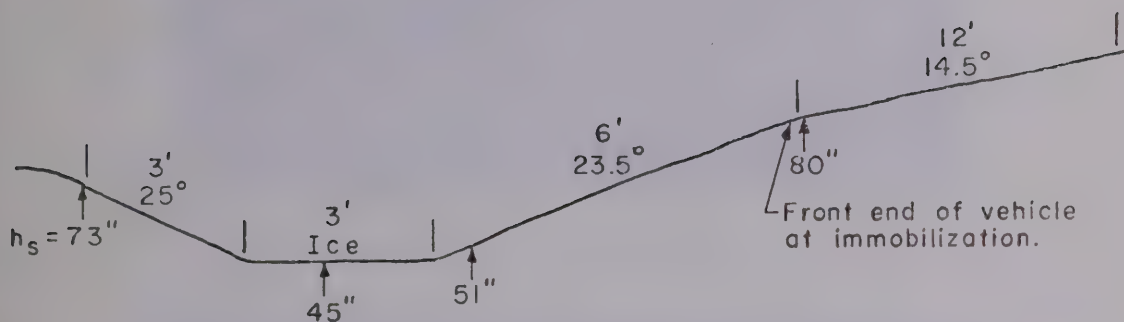


Figure 11

Photos 3, 4 and 5 show the crossing sites, with No. 5 showing point of immobilization.



Photo 3. Creek crossing.



Photo 4. Creek crossing.



Photo 5. Creek crossing

Photo 6 is a shot of No. 5 in June. Note the drastic change caused by the snow cover. In the summer, all three sites were impassable, the alder brush setting up a solid wall.



Photo 6. Creek crossing in summer.

Geometric obstacles are shown in Photos 7, 8 and 9; a $5\frac{1}{2}$ -ft vertical wall earth bank, a 42-in. solid walled step and a 42-in. V-trench.



Photo 7. $5\frac{1}{2}$ -ft earth bank.



Photo 8. 42-in. step.

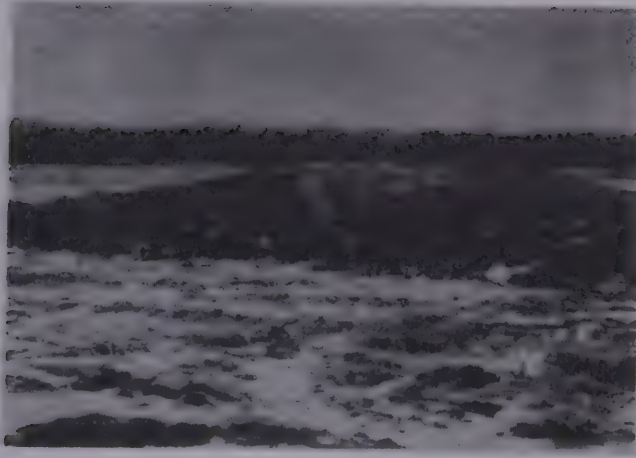


Photo 9. 42-in. V-ditch.

The same obstacles under snow cover appear as shown in Photos 10, 11 and 12 and Figures 12, 13 and 14.



Photo 10. $5\frac{1}{2}$ -ft earth bank.



Photo 11. 42-in. step.



Photo 12. 42-in. V-ditch

5½-ft earth bank

Density:

<u>Depth</u>	<u>g/cc</u>	
Surface	0.12	
6 in. below	0.29	Crusts @ 9", 14" and 17"
12 in. below	0.28	
18 in. below	0.38	
24 in. below	0.40	

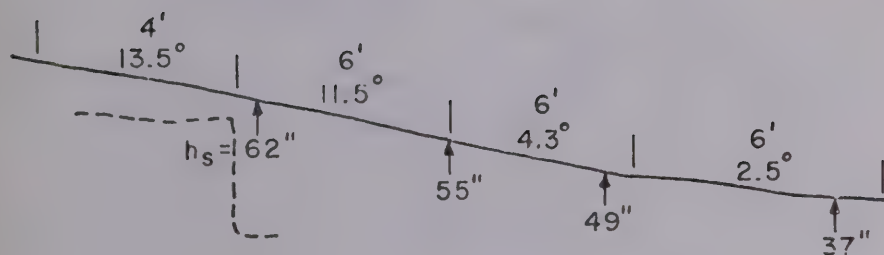


Figure 12

42-in. solid wall

Density:

<u>Depth</u>	<u>g/cc</u>
Surface	0.22
6 in. below	0.31
12 in. below	0.36
18 in. below	0.34

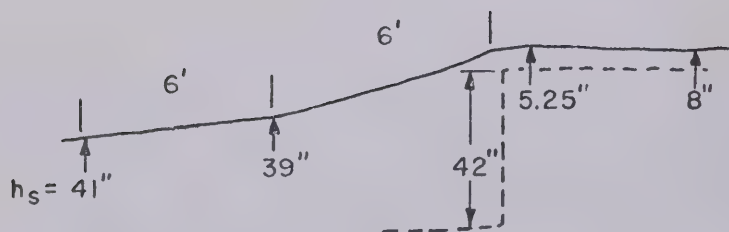


Figure 13

V-Trench

Density:

<u>Depth</u>	<u>g/cc</u>	
Surface	0.15	Ice layers @ $3\frac{1}{2}$ in.,
6 in. below	0.37	5 in., 7 in., 10 in.
12 in. below	0.36	and $12\frac{1}{2}$ in. below surface,
18 in. below	0.39	$\frac{5}{8}$ in. thick @ $12\frac{1}{2}$ in.
24 in. below	0.42	

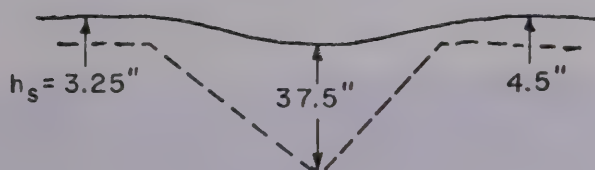


Figure 14

With V-trench uncovered, Photo 13, it becomes an immobilizing obstacle,
Photo 14.



Photo 13. V-ditch uncovered.



Photo 14. Immobilizing obstacle.

SOME CONCLUSIONS

The effect of heavy snow cover on obstacles has been illustrated by tests conducted in northern Michigan. Annual snowfalls well over 200 in. are not uncommon for this area. The limited tests conducted over snow covered obstacles in an area with level snow depths between 3 and 4 ft has clearly shown the masking effect that the cover provides. Obstacles greater than 5 ft high when uncovered become gentle slopes when covered. Prevailing winds affect the drifting character of the cover but the smoothing effect of heavy snow drastically changes the geometry of obstacles. To illustrate further this effect but in an area much different -- the Far North near Point Barrow, Alaska -- where annual precipitation in the form of snow is only several inches, the drifting and transport by the winds has the same masking effect on obstacles, changing them into a smoothed sloped or undulating terrain, Ref. 8. Heavy cover also greatly alters vegetative cover, especially low lying heavy brush. The questions remaining unanswered by the preliminary tests are the effects of and the relationships between snow depths of consequence and obstacles, e.g., two obstacles while uncovered may be problems for vehicle travel but with a 6-in. snow cover one may become obscured while the other may not be affected. The questions of snow cover and its affects on obstacles and vehicle travel cannot be fully understood or resolved until vehicle tests are conducted at lesser snow depths where snow depth/obstacle height relationships can be established. Also, other vehicles that are used in snow operations should be tested.

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